Advancements in Understanding Plasma Cleaning

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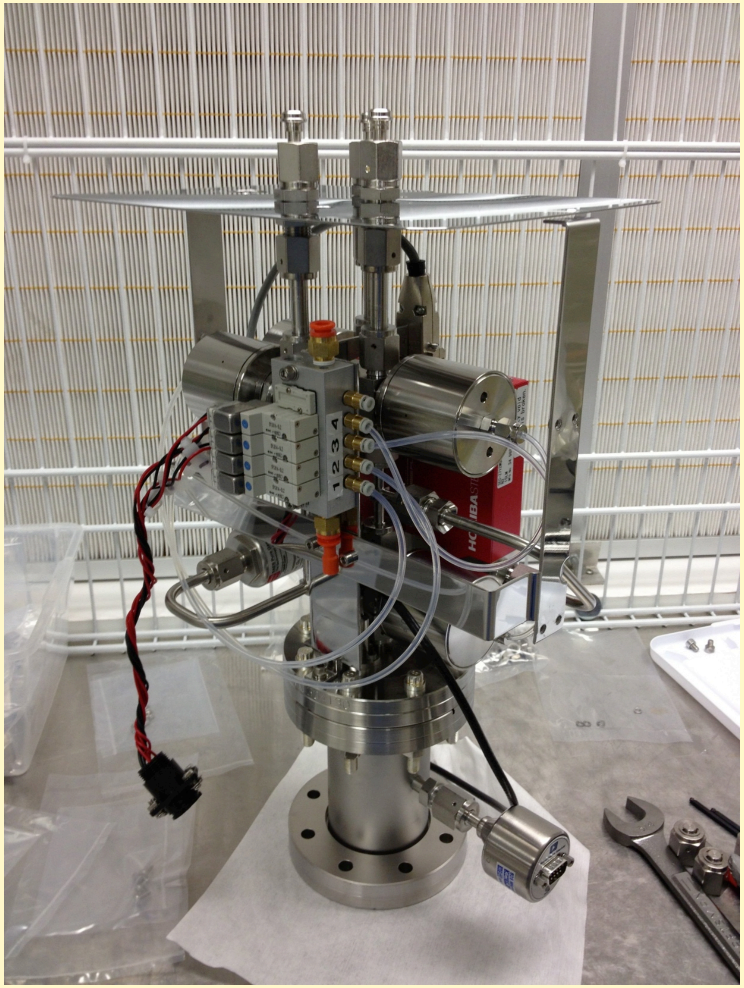
Outline

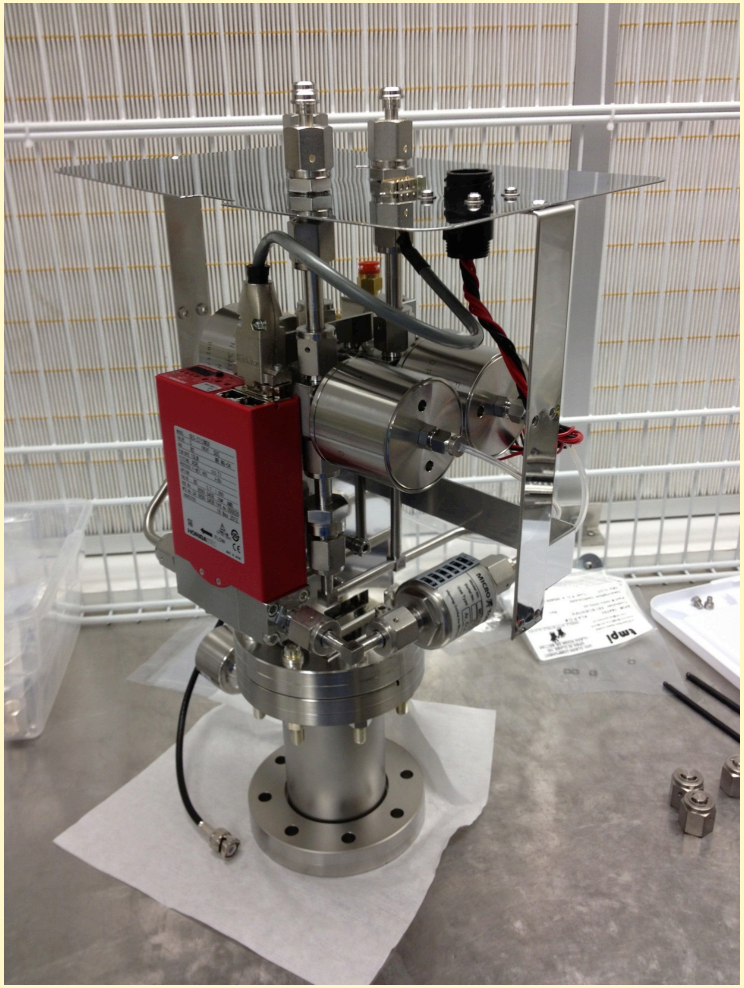
- EUV-compatible plasma system
- Cleaning Rate Metrology
- Parametric study
- H_2 Plasma Effects on Materials
- Future Directions
- Conclusions

Background and motivation

- Ru-capped MLMs oxygen sensitive
- Established that cleaning needs to be H_2 based
- Prior XEI efforts at plasma cleaning for EUV used inappropriate materials/methods
- Partnered with SEMI equipment OEM to develop advanced plasma cleaning system
- Delivered April '13, passed initial cleanliness analyses, more detailed studies underway

EUV-compatible plasma system





Details available at poster session P28

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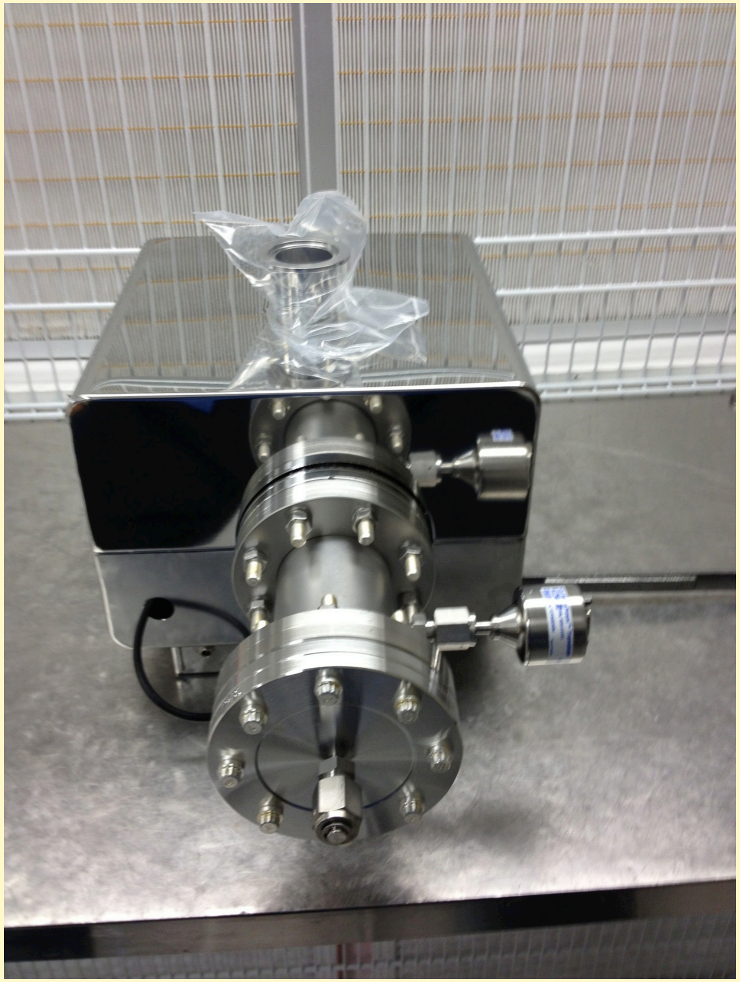
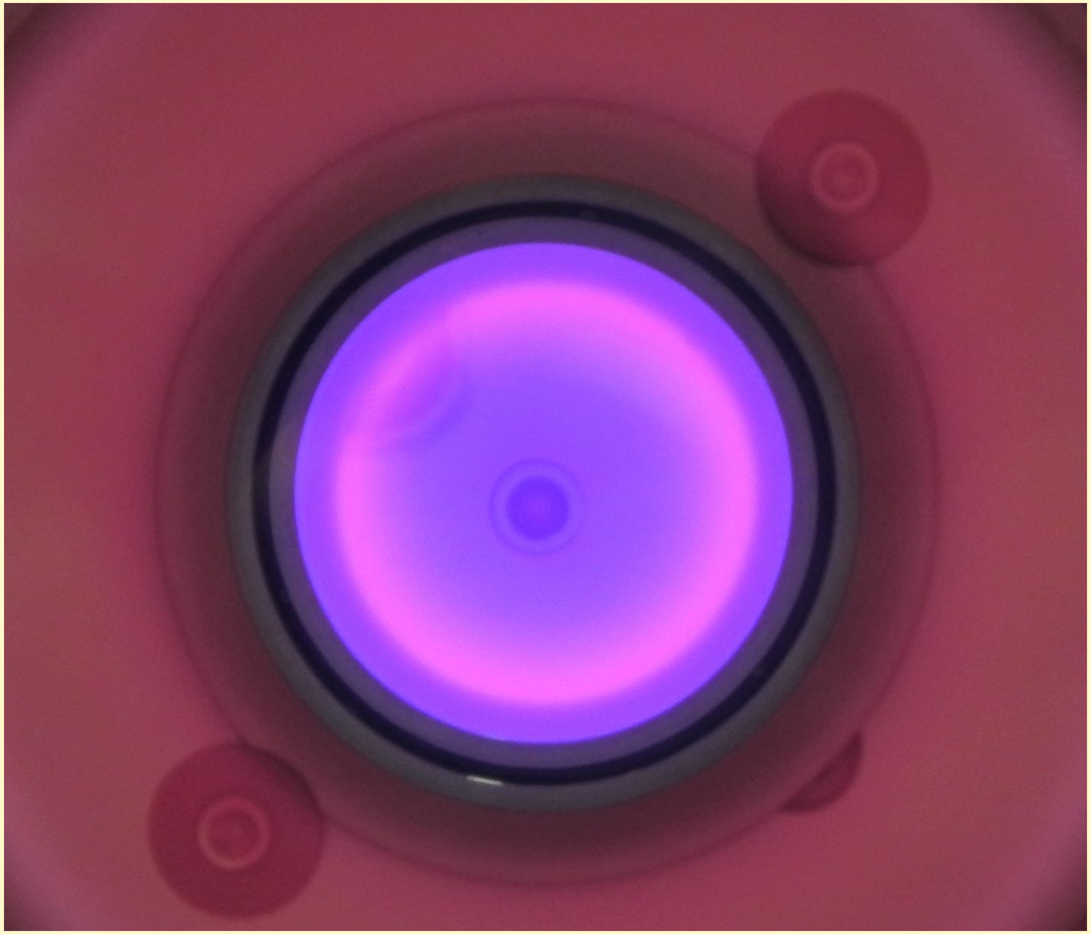
EUV-COMPATIBLE PLASMA SYSTEM





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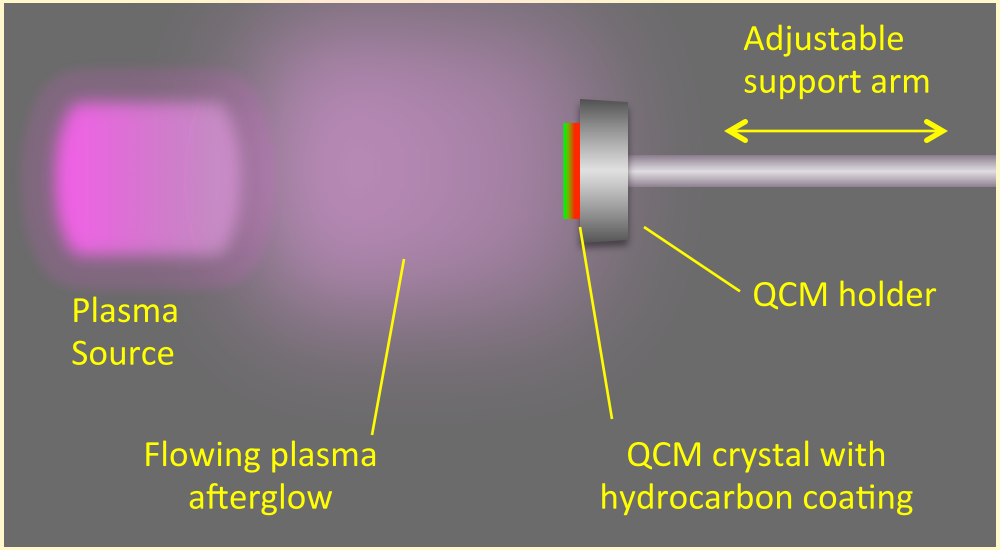
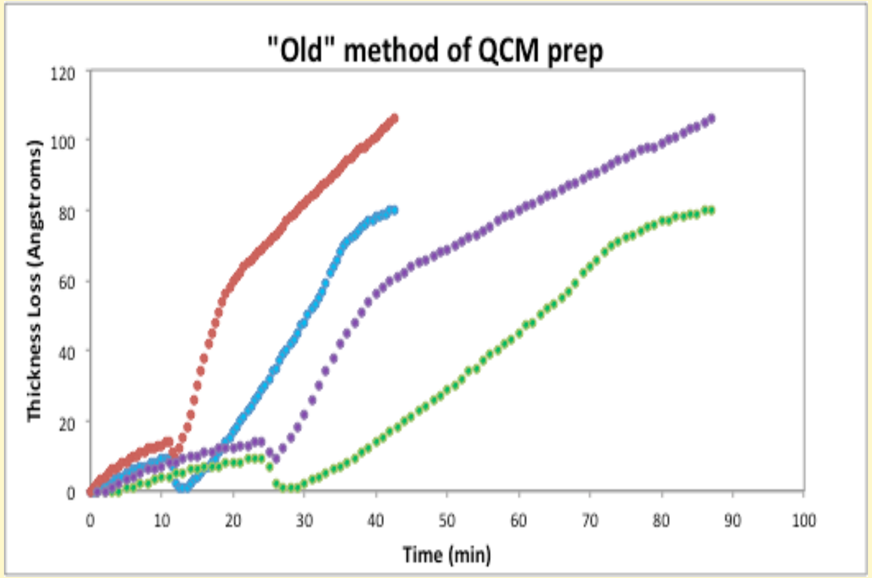
Quantifying Plasma Cleaning

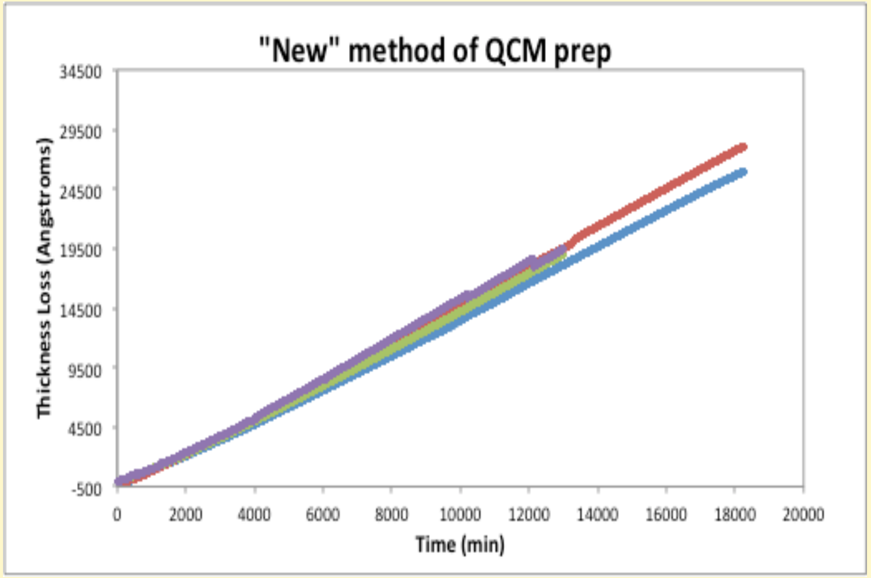
- Difficult to optimize design of plasma and process without quantitative metric
- Hydrocarbon (HC) contamination varies: composition, carbon bonding (type, density), extent of polymerization
- Solution:
  - Use established quartz crystal microbalance (QCM) tools
  - Devise reproducible deposition of hydrocarbon-based solid film on QCMs
  - Plasma clean HC, record Δ(thickness) vs. time to estimate cleaning rate



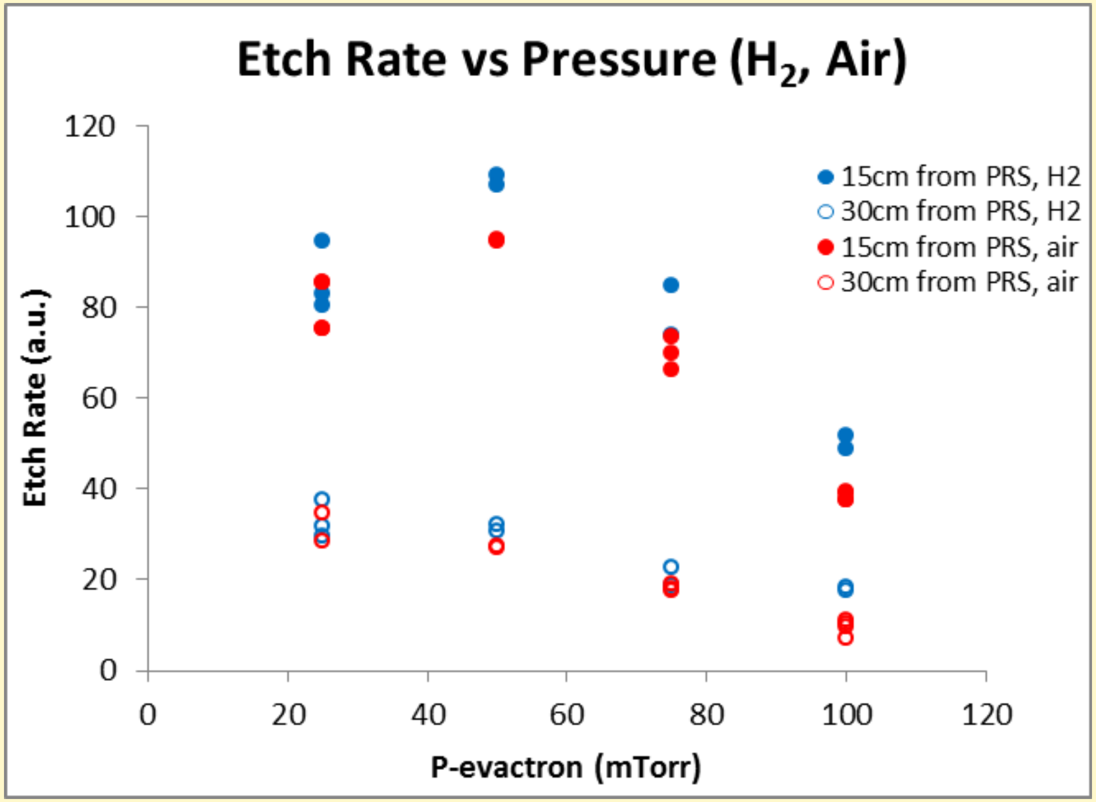
Quantifying plasma cleaning

- Needed to develop process for deposition of hydrocarbon proxy with inter- and intra-sample repeatability
- Need is stability for plasma cleaning process development- practical cleaning rates will vary



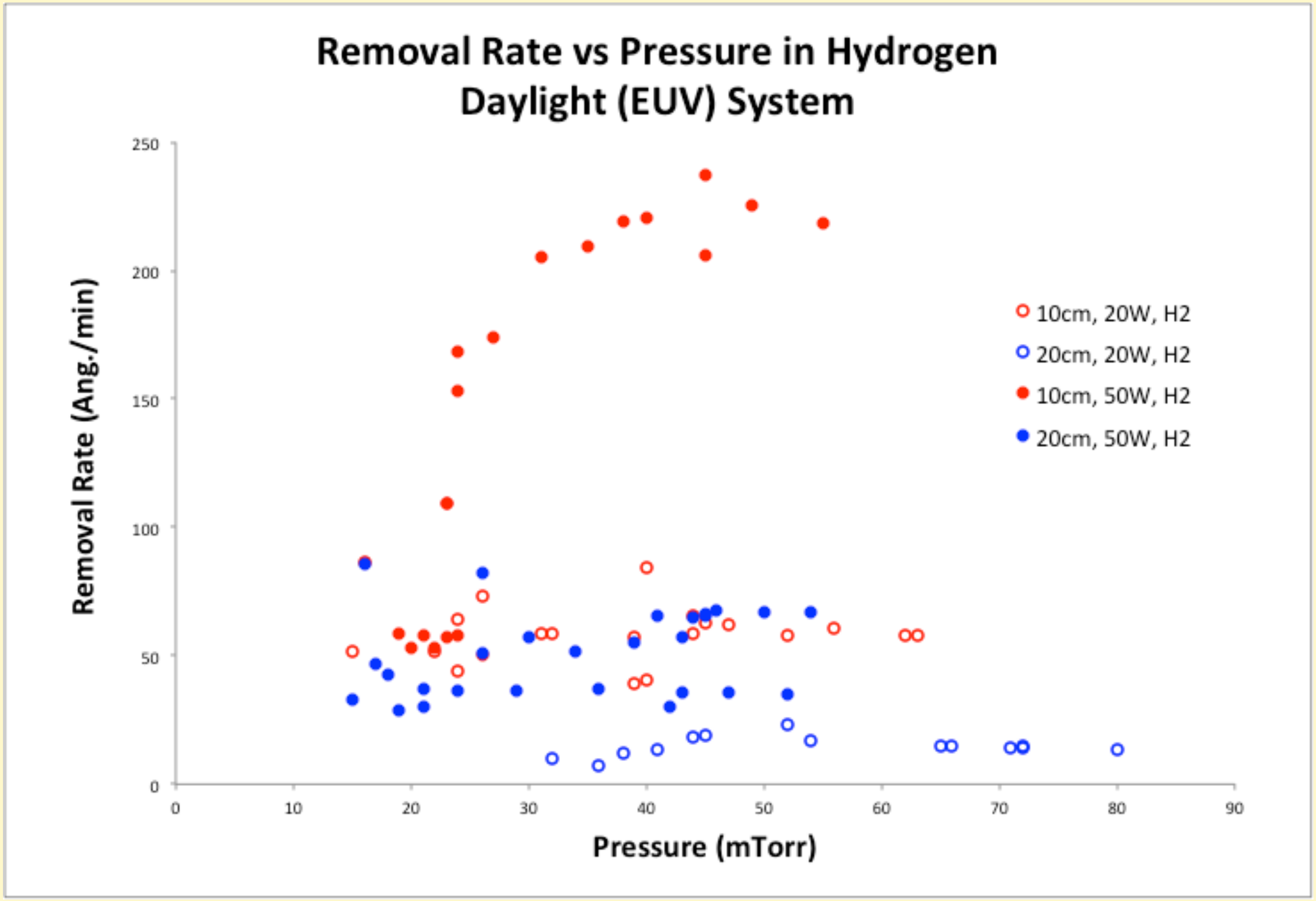


Removal rates standard Evactron



Measured in 10 liter chamber

Removal rates Daylight system



For this chamber (two 6”CF crosses) and pumping combination:

- < 30 mTorr appears to deplete reactant feedstock
- Cleaning rate more than linear with plasma power

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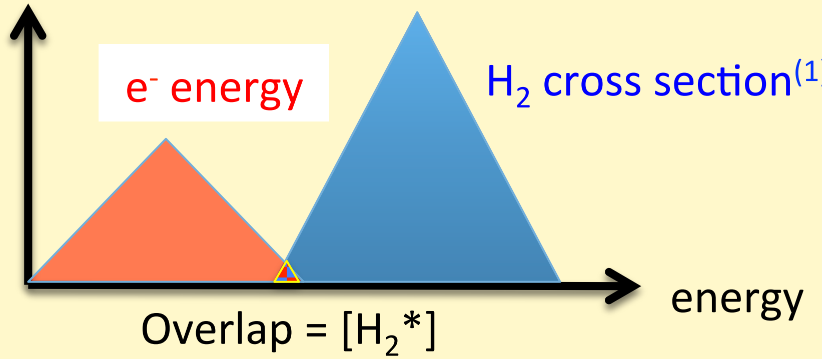
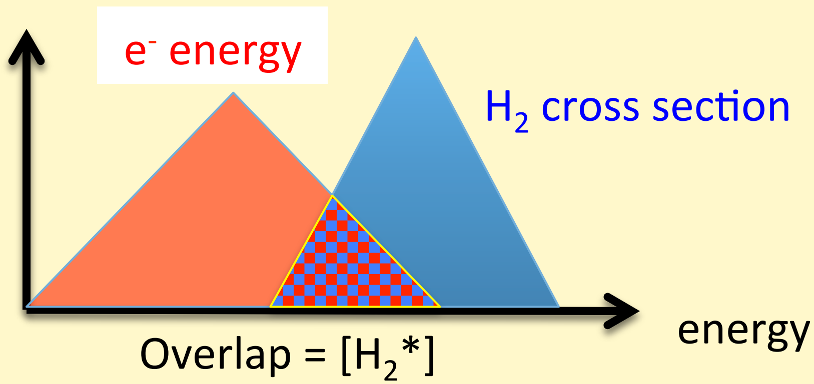
Cleaning rate dependence on plasma power

- Radical production is result of overlap of electron energy and excitation cross section



- But double power and both # and energy of e^- go up



(1)- For oxygen, Itikawa, *J. Phys. Chem. Ref. Data*, 38(1), 1 (2009).

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Chamber geometry effects

Comparing data from last two data slides:

- 10 ℓ chamber, 50 mTorr, 20 W:

  110 Å/min. @ 15 cm away

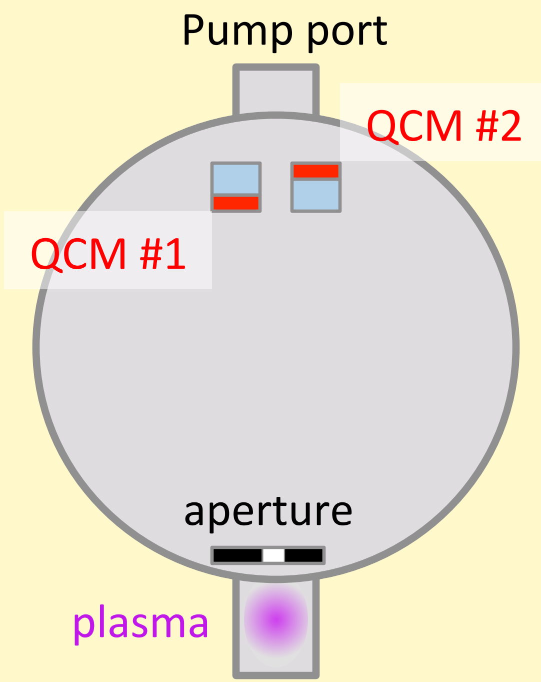
  30 Å/min. @ 30 cm away

- 30 ℓ chamber (CF crosses), 50 mTorr, 20 W:

  15 Å/min. @ 20 cm away

➔ Chamber volume/features, pumping, transport vector play a strong role in cleaning

Pressure and geometry effects: an example



- 10 litre chamber
- 2 QCMs
  - One facing plasma
  - One facing pump port
- Aperture to optionally constrict plasma effluent
- Measured cleaning rates at different pressures

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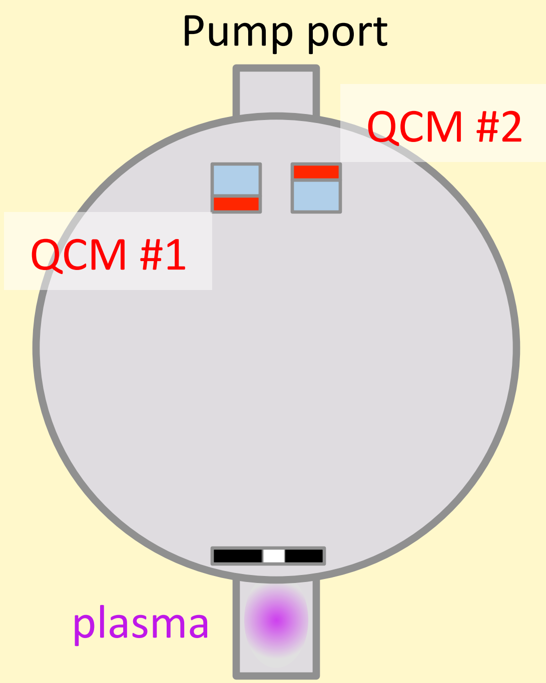
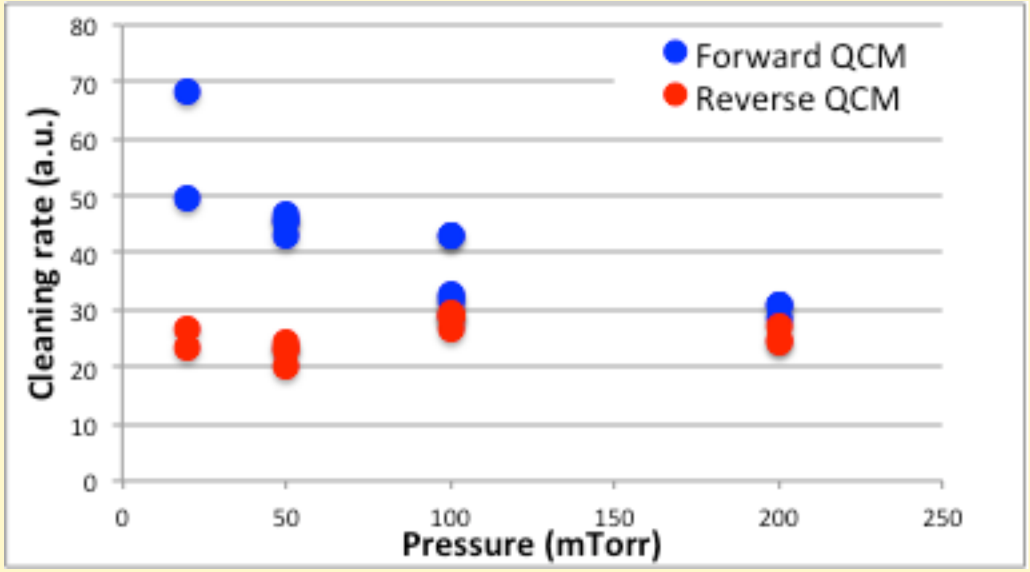
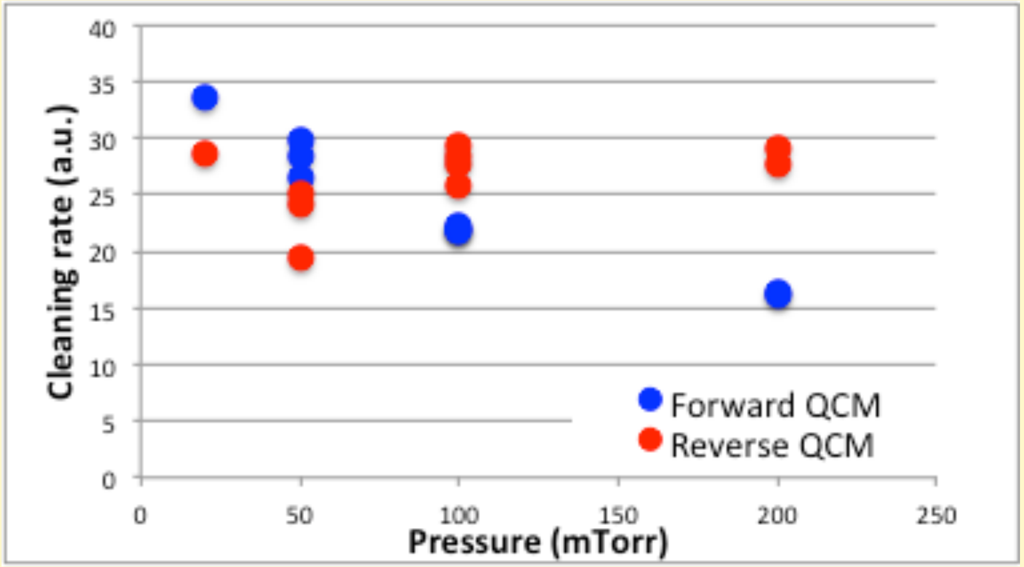
Pressure and geometry effects: an example



Apertured



Open



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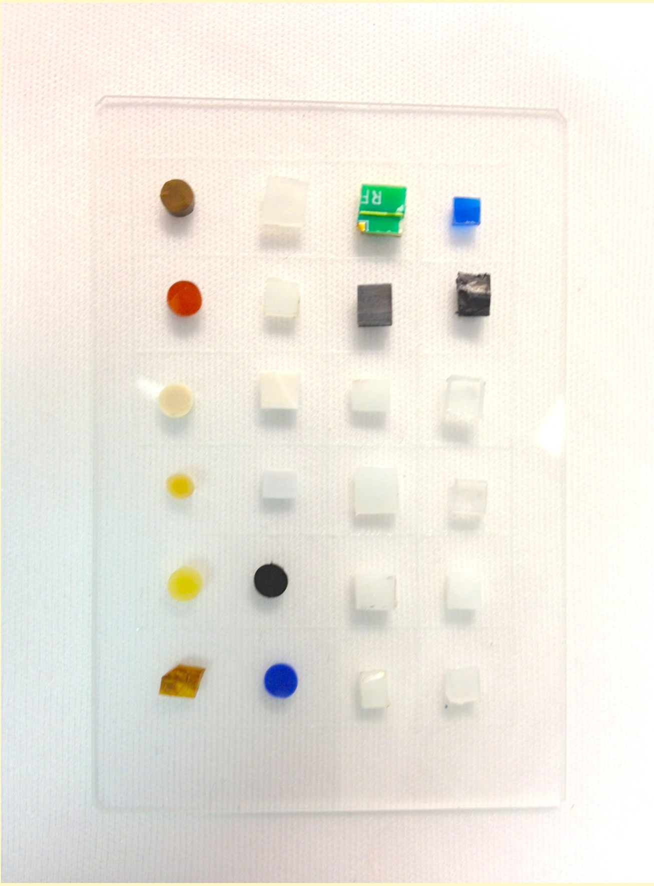
Study of plasma effects on various materials

- Frequent area of concern: how does plasma cleaning affect other materials?
- To address this question, samples of 36 materials were collected and then mounted on glass slides
- Materials included common plastics/polymers, lubricants, and o-rings
- Fixing of some samples performed using cyanoacrylate glue; lubricants applied through mask to form 6 mm x 0.1 mm disk

Study of H_2 plasma effects on various materials



- **Lubricants**
  Krytox   Apezion-L   C5-A
  6300   6200   OC Seven
  Braycote 1632
- **O-ring materials**
  Viton   Low-fill Viton   Buna nitrile
  Silicone   Fluorosilicone   Kalrez 8085
  Vespel   Kalrez ultrapure
- **Plastics/polymers**
  ABS   PTFE   Plexiglas
  Delrin 127UV, 100P, 527UV   PVDF
  Polycarbonate   HDPE   UHMW-P
  Polypropylene   PVC   Acrylic
  Nylon   PEEK   EPDM
- **Others**
  Kapton (tape)   Teflon (tape)
  FR-4 (PCB)

Dupont   Nye   MPT
Loctite   Parker   Gore

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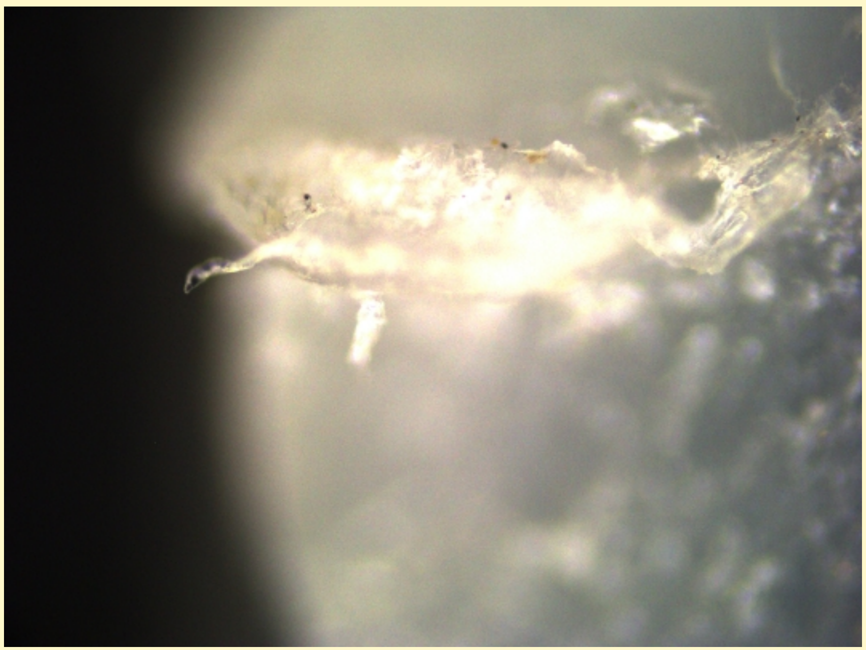
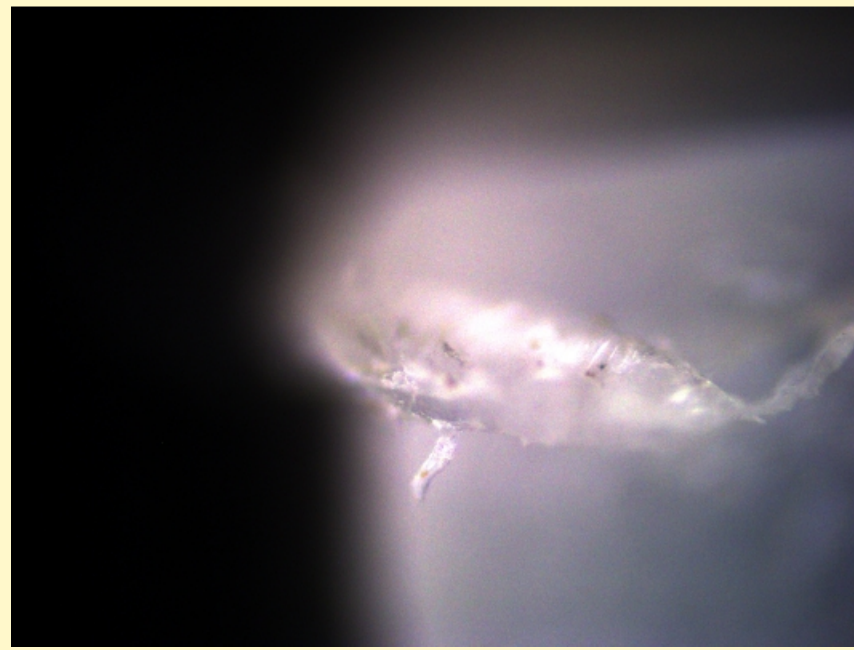
Study of plasma effects on various materials

- 2 hrs. of H_2 plasma @ 50 Watts
- All images 100x

Acrylic





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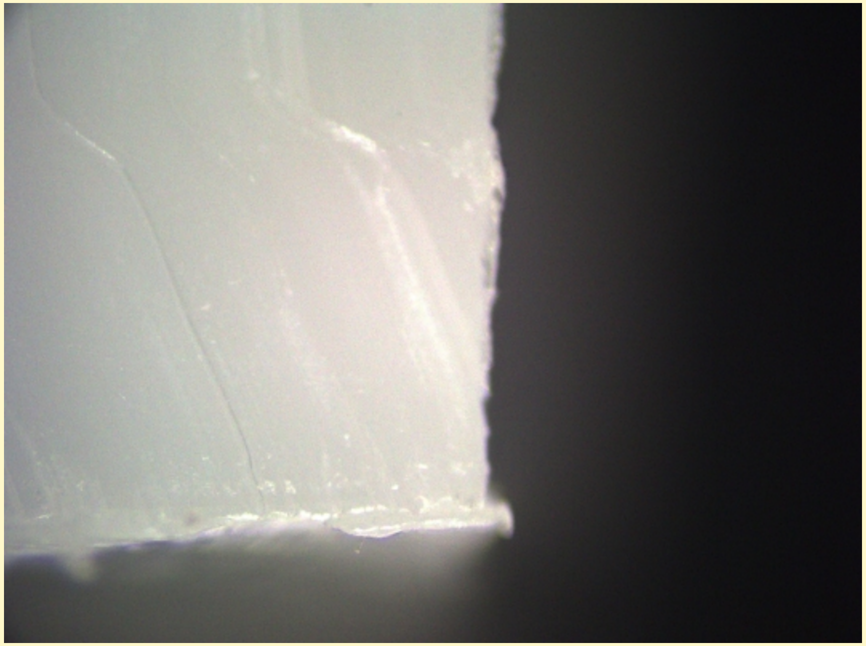
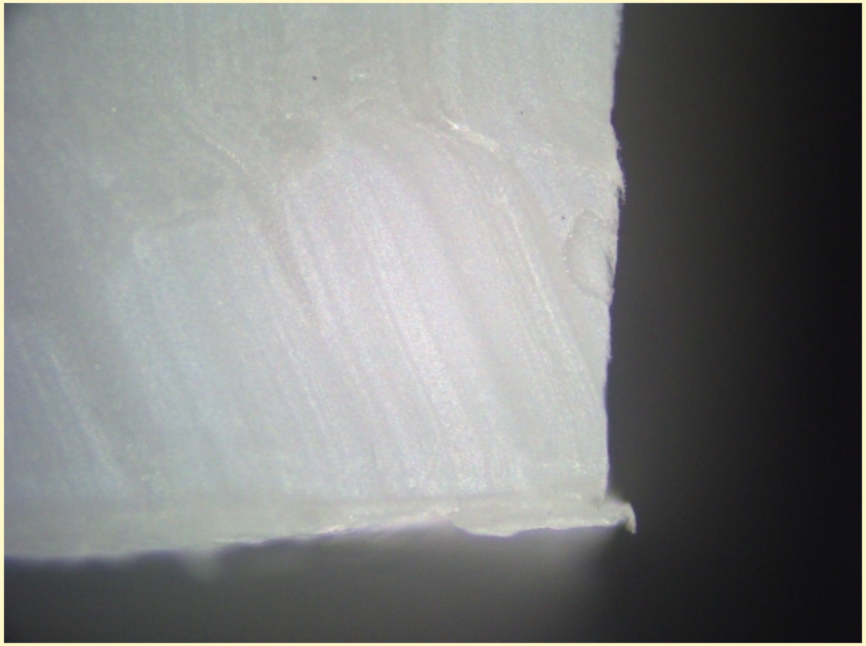
Nylon





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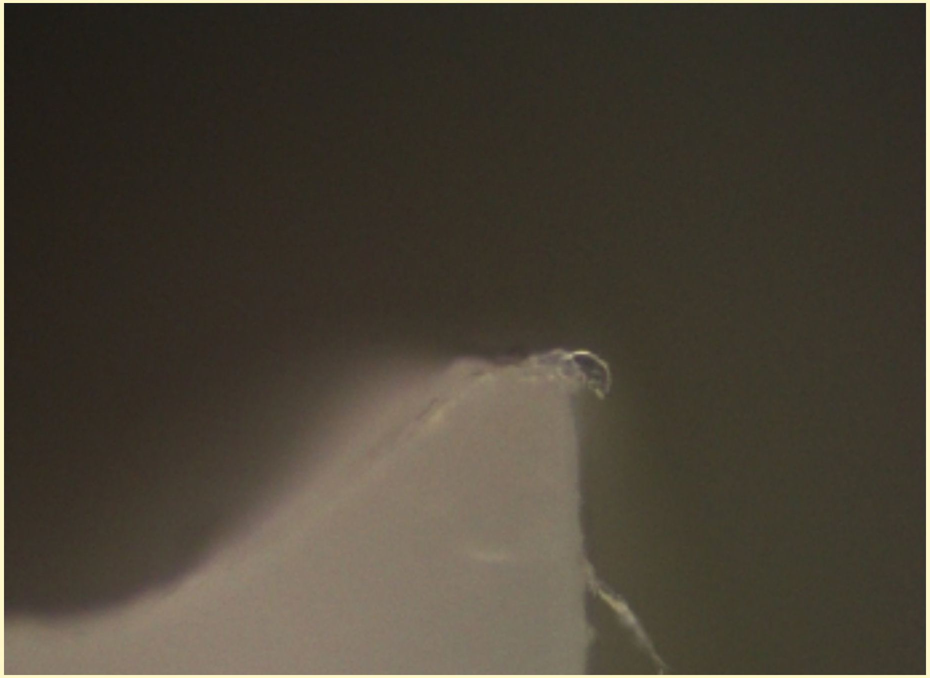
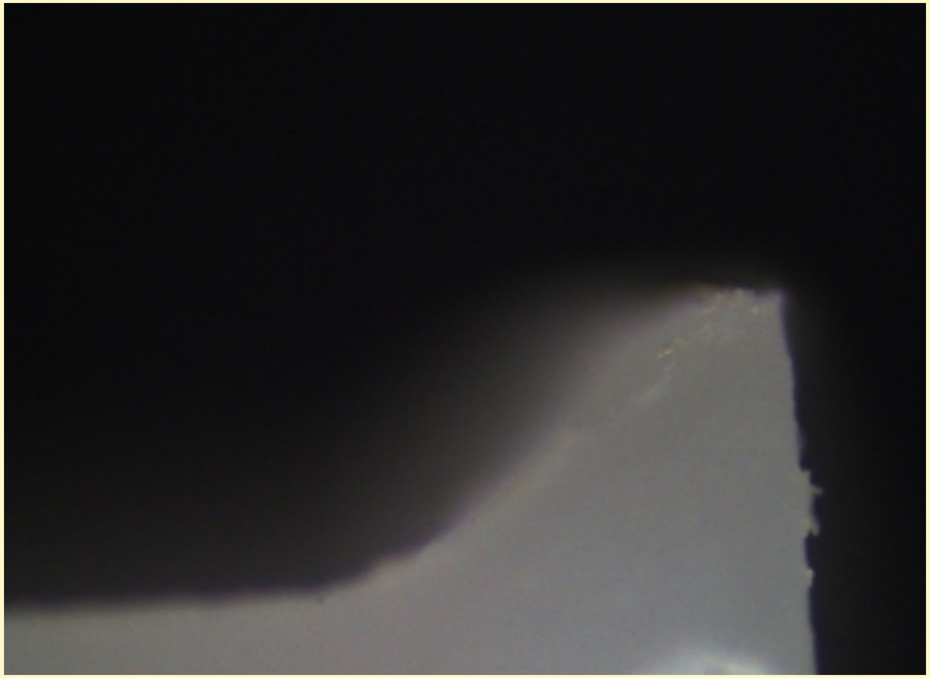
Delrin 127 UV





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Study of plasma effects on various materials

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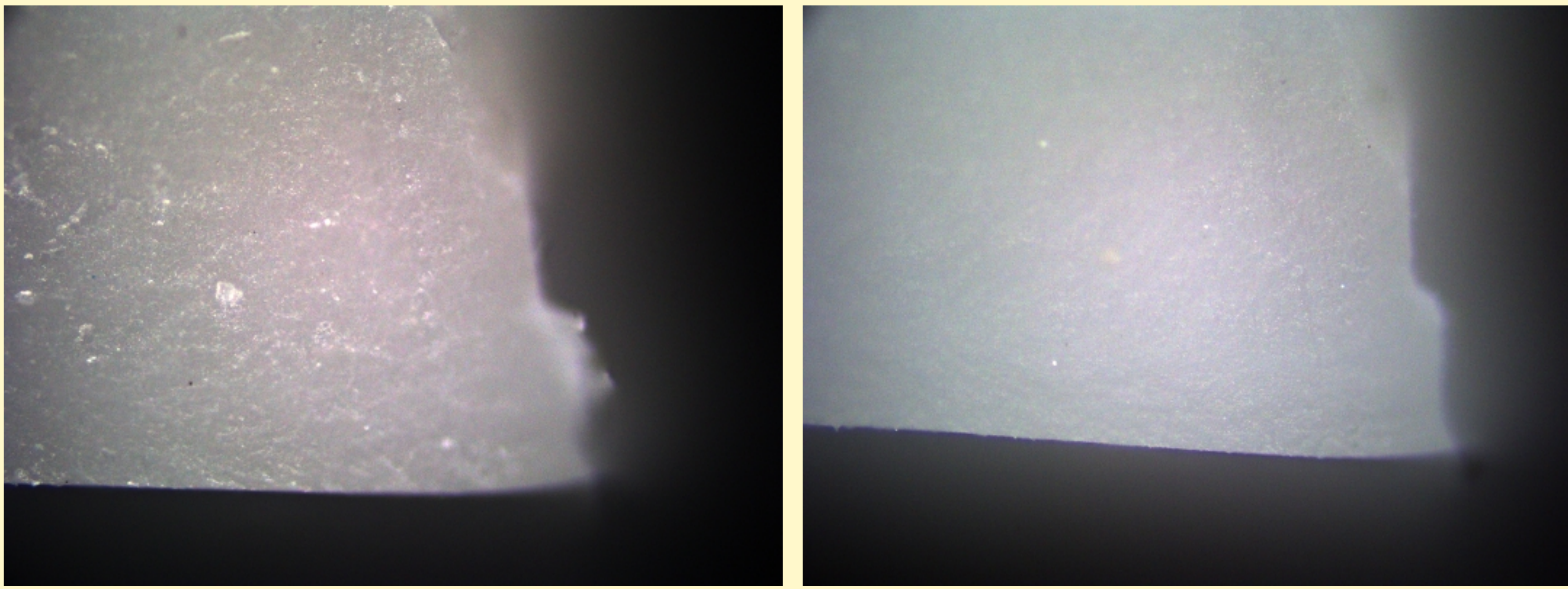
Delrin 527 UV



Study of plasma effects on various materials

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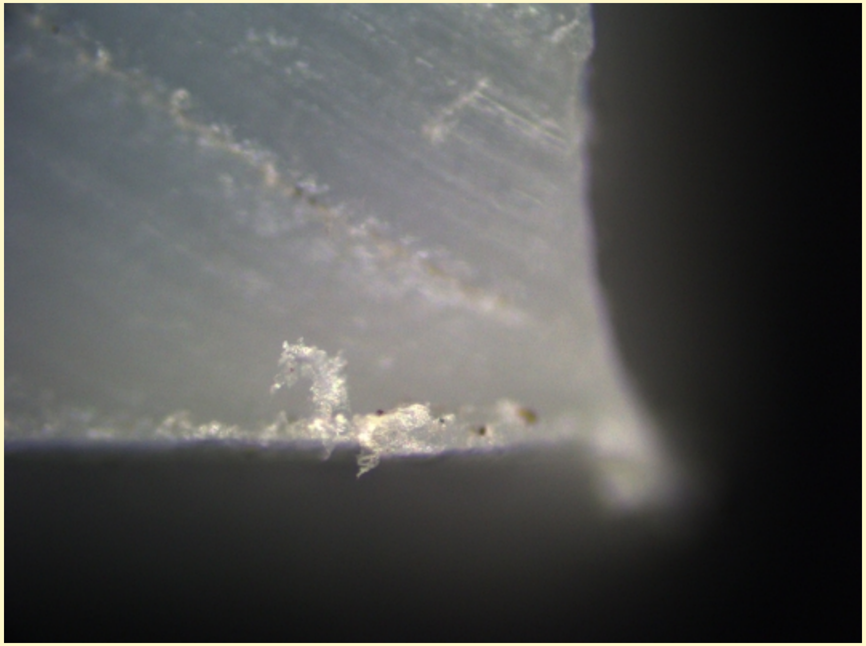
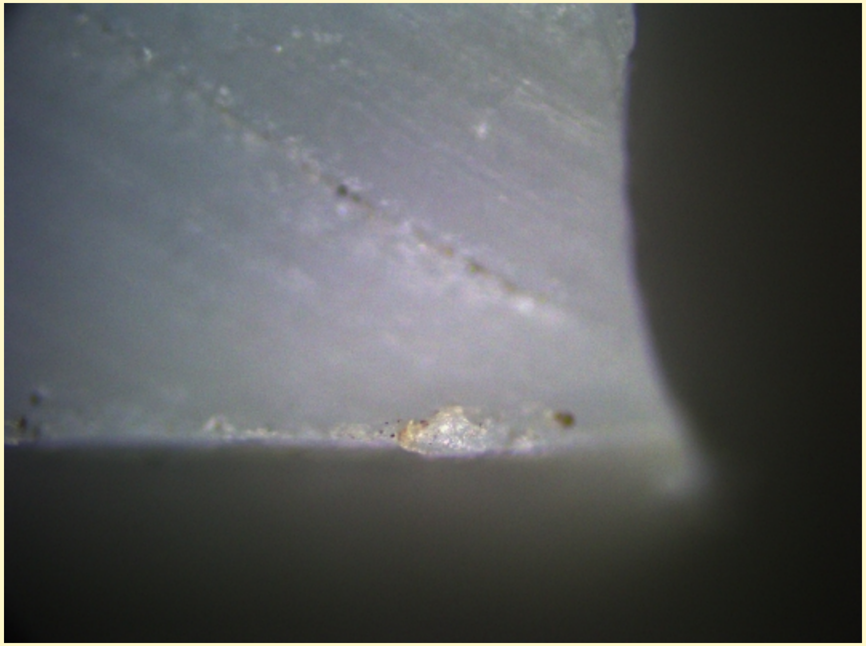
UHMW-P





Study of plasma effects on various materials

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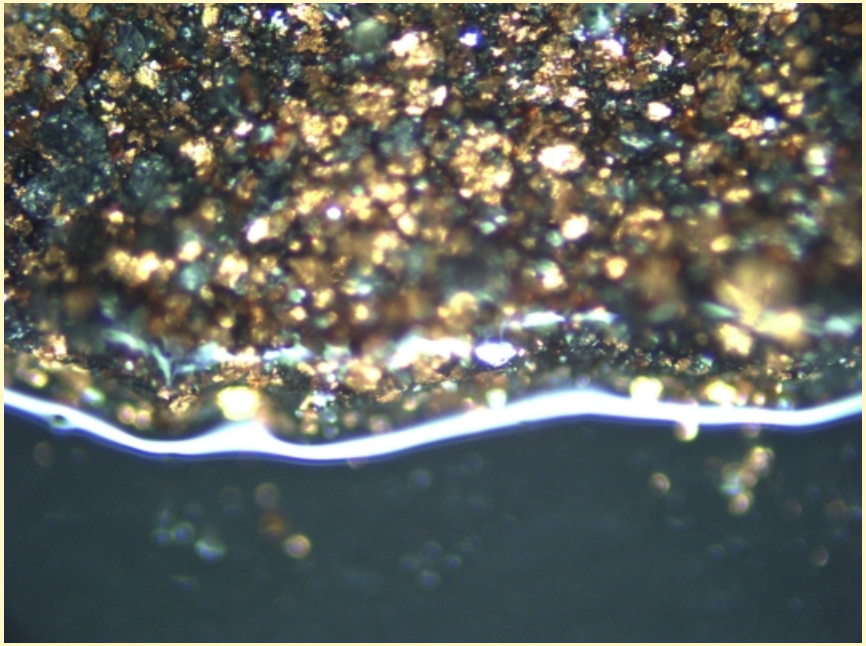
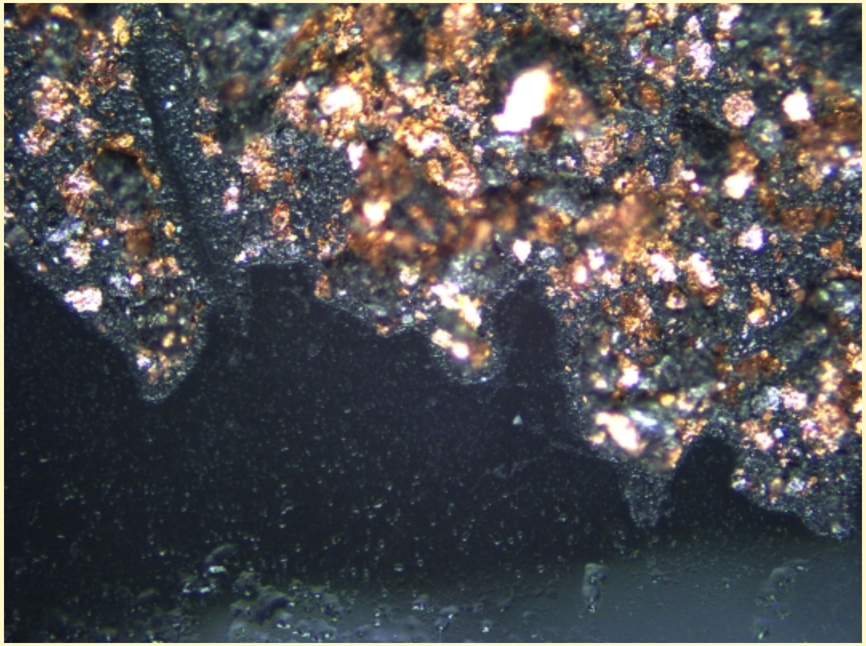
C5-A





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Study of plasma effects on various materials

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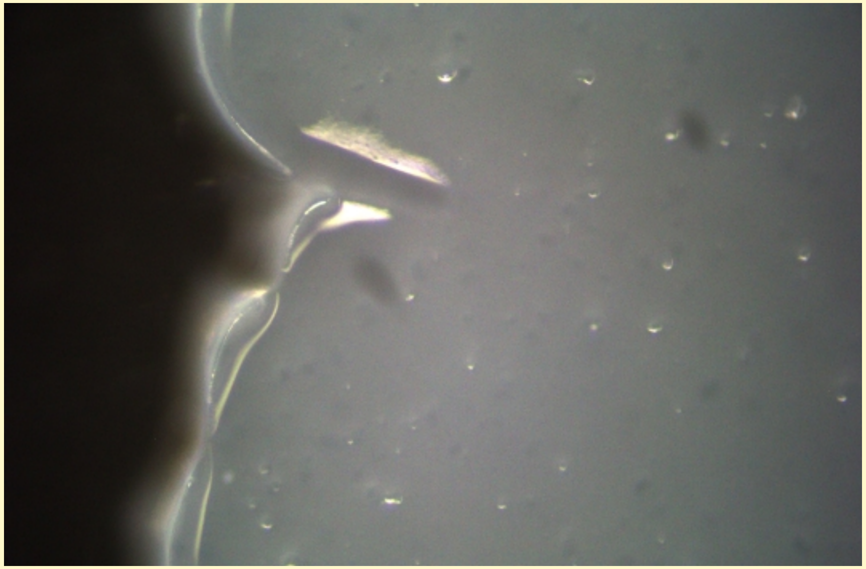
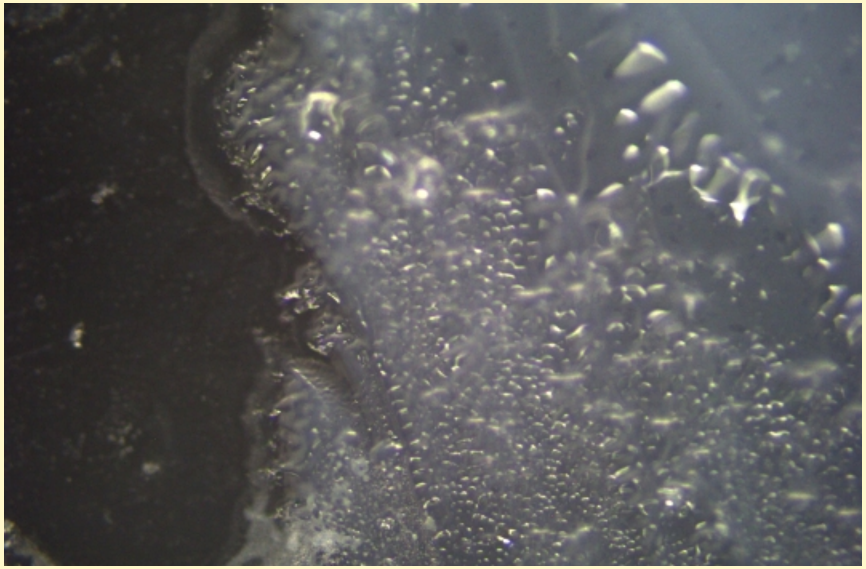
Nye 6300





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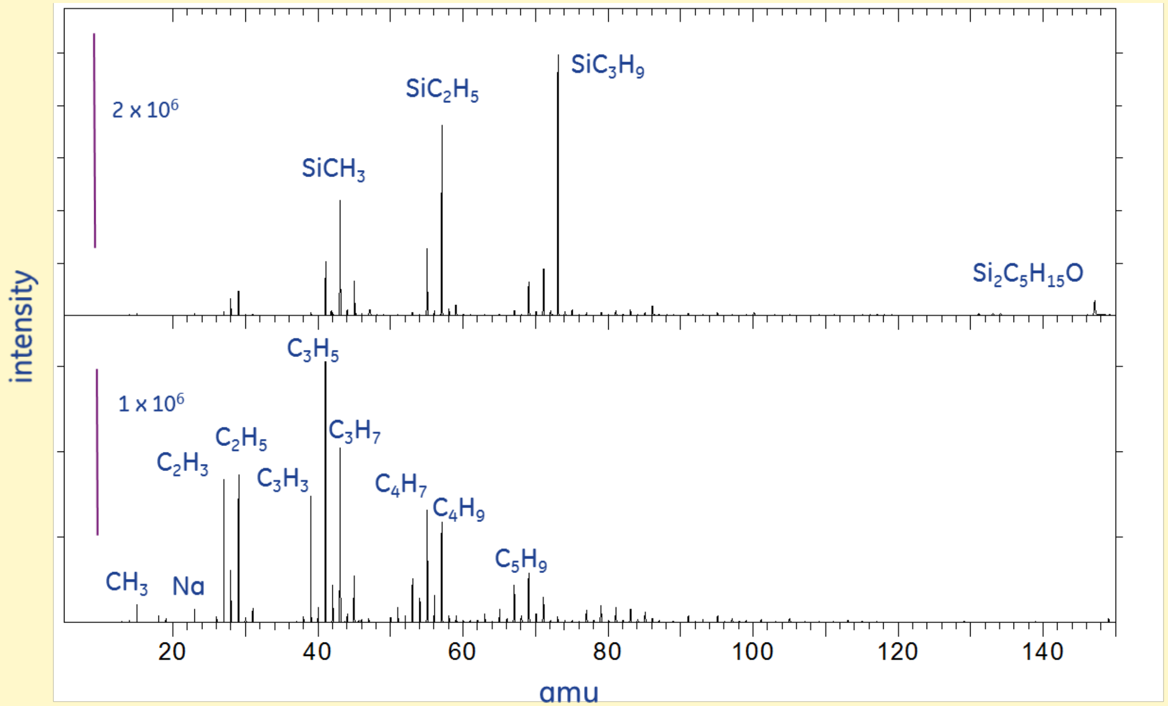
Recent result (using N2-O2 plasma)

- Plasma removal of PDMS* silicone from paper coupon using ToF-SIMS

Prior to plasma exposure

After 20 min. and 10 W plasma exposure



*- polydimethylsiloxane

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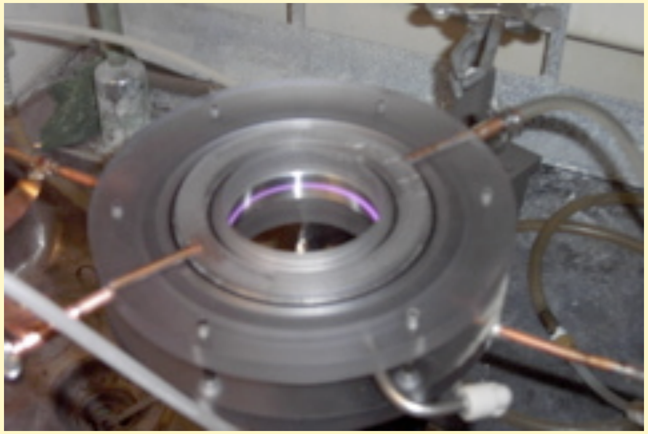
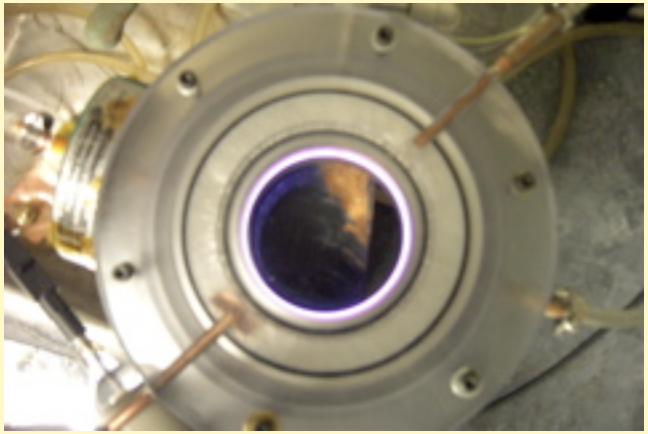
Future directions

- Alternative gas chemistries (e.g., Ruzic @ Illinois, e.g. *J. Vac. Sci. Technol. B 31(1), Jan/Feb 2013)*
- Localized cleaning systems for optical elements
  - TEM wand
  - Prior work (1): Circular plasma

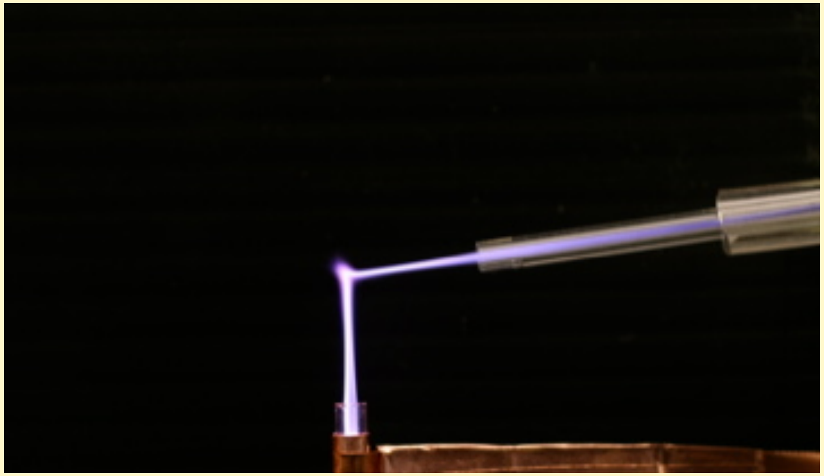


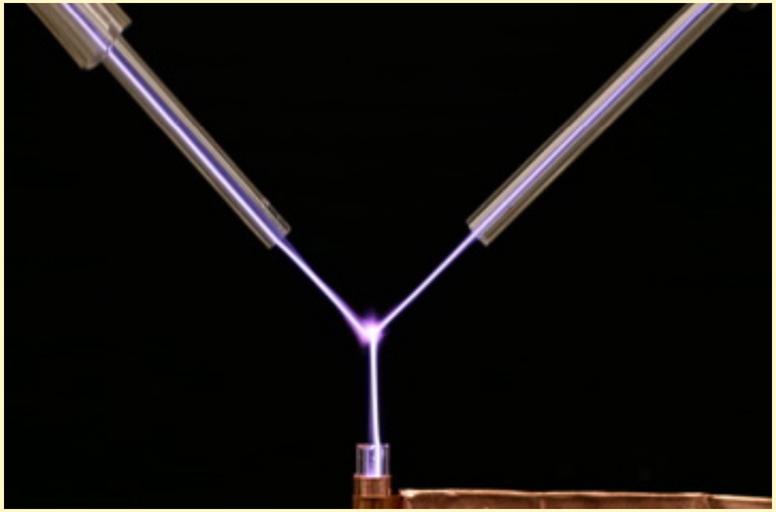


Future directions (continued)

- Prior work (2): Needles/jets

  - Can be *arrayed*





Conclusions

- New electrode design capable of 50 W plasma power (> 150 W in limited tests)
- For both air (O_2-N_2) and hydrogen (H_2) it was found that gas pressure selection is a key for maximizing cleaning rates
- Higher pressures increase scattering by the gas
- Lower pressures required to reach farther

  -Reduced pressure smaller effect on reactant concentration (since $N_{gas} >> n_{electron}$)
- A stable method for hydrocarbon film preparation allows for parametric studies of plasma cleaning
- Material removal can affect more than just typical hydrocarbons